PERFORMANCE OF THE ION CHAIN AT THE CERN INJECTOR COMPLEX AND TRANSMISSION STUDIES DURING THE 2023 SLIP STACKING COMMISSIONING

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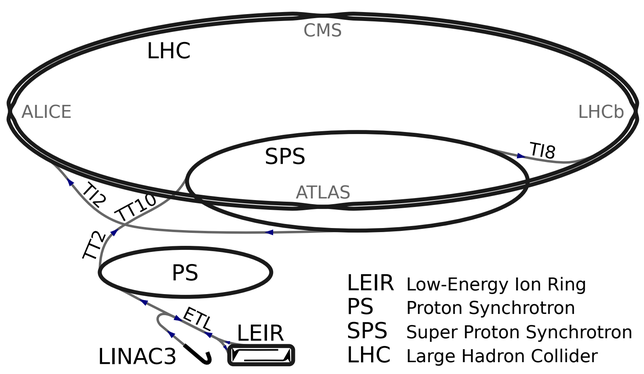
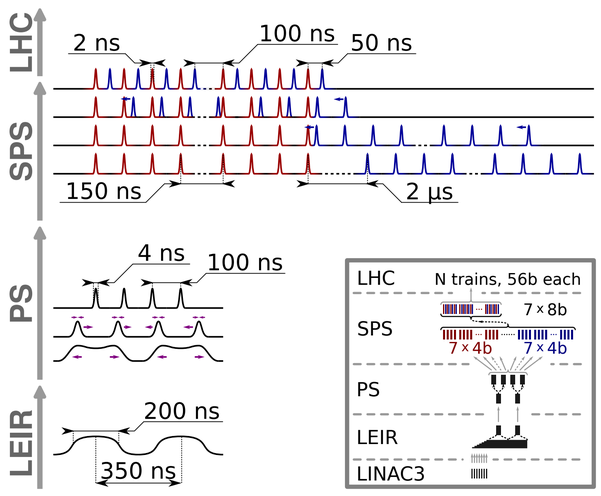
CERN ion injector complex

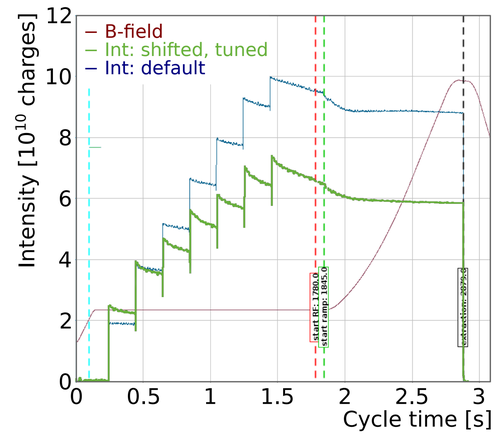
- **Linac3**
  - Source: Pb^{29+}
  - Stripping to Pb^{54+}
  - 4.2 MeV/n
- **LEIR**
  - Multiturn injection
  - Accumulation of seven 200 µs-long pulses from Linac3
  - electron-cooling
  - RF capture: 2b
  - acceleration to 72 MeV/n
- **PS**
  - Bunch spliting (2b → 4b)
  - Bunch separation at extraction: 100 ns
  - 6 GeV/n
- **SPS**
  - Long injection plateau: 48 s
  - 14 injections from PS
  - Slip-stacking
  - Bunch separation at extraction: 50 ns

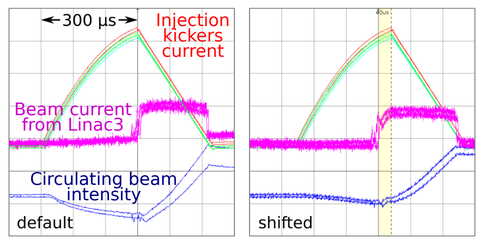




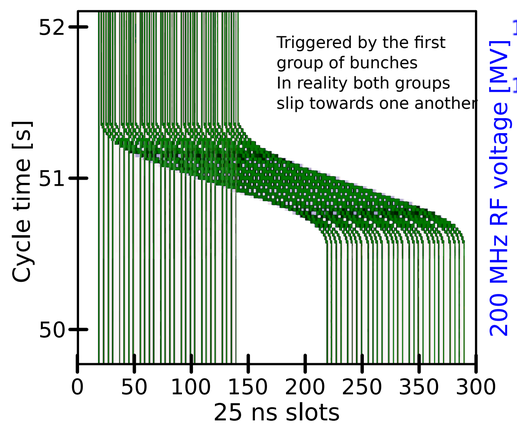
Accumulation in LEIR

- Issues during beam commissioning
  - **Losses** of cirulating beam at the fast kickers' ramp-up 300 µs before the next **injection**
  - Reduced efficiency of the electron **cooler**
  - Irregularities with front-part of the beam coming from Linac3
- Mitigations
  - **Tuning** Cavity2 and Cavity3 expert paremters in Linac3 to improve pulse stability and leading edge slope
  - **Increasing pulse length** from Linac3 from 200 to 240 µs **and delaying** the LEIR injection system pulsing by 40 µs to avoid injecting the front, irregular part of the beam
  - **Increasing** the electron-beam **current** to enhance cooling

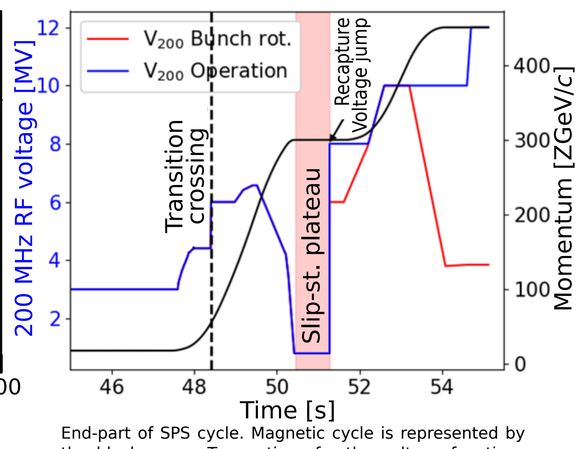




SPS slip-stacking



Time evolution of 56 SPS bunches

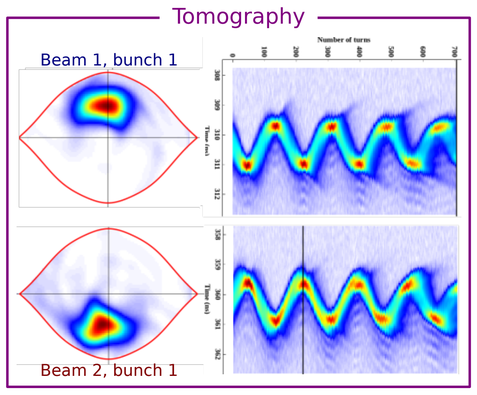


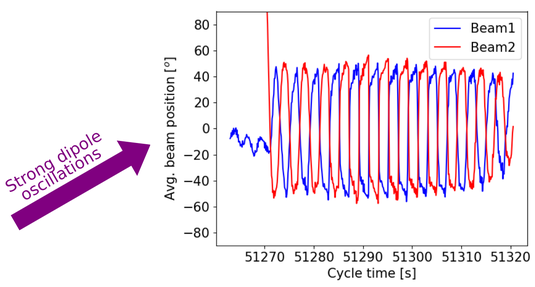
End-part of SPS cycle. Magnetic cycle is represented by the black curve. Two options for the voltage functions are shown in red and blue

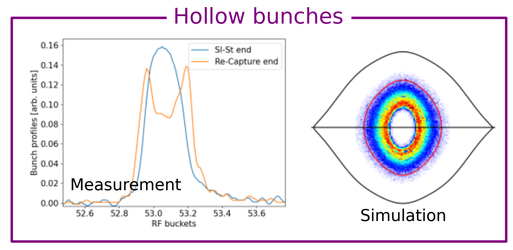
→ **Reduction** of **bunch spacing** from 100 ns to 50 ns

- 14 batches of 4 bunches each are **injected** into SPS from PS
- The beam is **ramped up** to intermediate slip-stacking plateau
- Two particle beams of different momenta and different RF frequencies **slip longitudinally** relative to each other in the same beam pipe
- When the two beams are in the correct longitudinal position, the full beam is recaptured with a non-adiabatic voltage jump at the average RF frequency

→ **Instabilities at recapture**

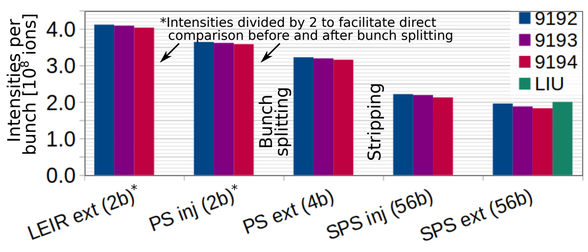




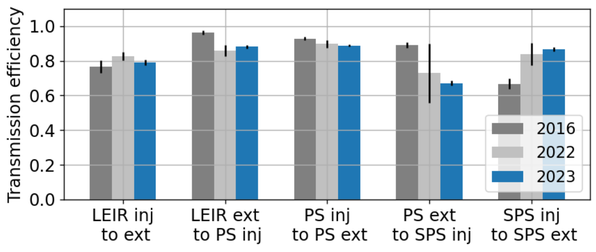


- Mitigation
  - Phase loop is disabled before voltage jump
  - Switch 800 MHz RF on at the moment of recapture
    → Increase beam stability and filament faster
  - Enable phase loop after filamentation
    → Repopulation of bunch center

Bunch intensities and transmission

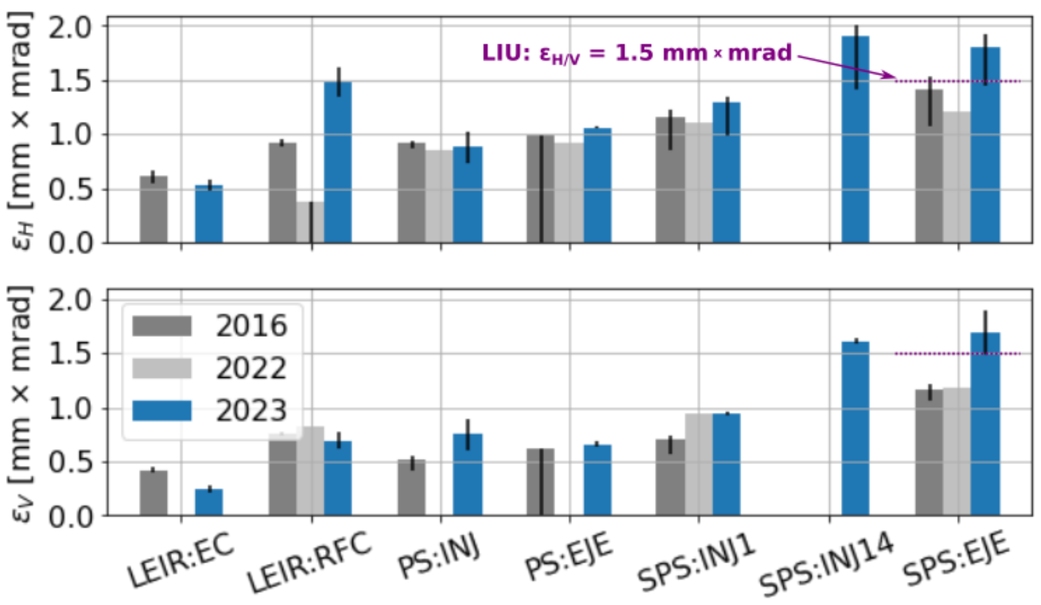


- Intensities per SPS-equivalent bunch in the first three fills of 2023 ion run
  - Beam scraping at SPS due to limitation of the LHC injection system
    → extracted intensity slightly below LIU
  - Most losses between PS ext and SPS inj
    → stripping and long injection plateau



- Transmission
  - Consistent across the years: 2016, 2022 and 2023
  - 2023: average of the first 3 LHC fills with 'stable beams'
  - PS extraction to SPS injection data from 2016 used DCBCT (incl. unbunched beam)

Emittances



- LEIR
  - Emittance LEIR:EC is measured just before switching e-cooler off
  - LEIR:RFC is measured at RF capture, 70 ms after switching e-cooler off
    → high 2023 ε_H - to be understood
- SPS
  - Data collected during slip-stacking com-missioning (before optimum was found)
  - INJ1 and INJ14 show how the emittance of the first 4-bunch batch evolves along the injection plateau

Summary

- Ion injectors are delivering beams at close-to-LIU parameters
- SPS slip-stacking is operationonal and up to specifications
- LEIR beam is not fully understood